

Faculty of Medicine
Biomedical Engineering

Master of Science Thesis

Development and Evaluation of a New Tablet Computer Application for the Therapy of Brain-Injured Patients with Aphasia

by

Silvan Januth

of Flims

Supervisors

Prof. Dr. sc. Tobias Nef and Prof. Dr. med. René M. Müri

Institutions

Gerontechnology and Rehabilitation Research Group,
ARTORG Center for Biomedical Engineering Research of the University Bern

Division of Cognitive and Restorative Neurology,
Department of Neurology Inselspital Bern

Examiners

Prof. Dr. sc. Tobias Nef and Prof. Dr. med. René M. Müri

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Abstract

Introduction

Language is the most important mean of communication and plays a central role in our everyday life. Brain damage (e.g. stroke) can lead to acquired disorders of language affecting the four linguistic modalities (i.e. reading, writing, speech production and comprehension) in different combinations and levels of severity. Every year, more than 5000 people (Aphasie Suisse) are affected by aphasia in Switzerland alone. Since aphasia is highly individual, the level of difficulty and the content of tasks have to be adapted continuously by the speech therapists. Computer-based assignments allow patients to train independently at home and thus increasing the frequency of therapy. Recent developments in tablet computers have opened new opportunities to use these devices for rehabilitation purposes. Especially older people, who have no prior experience with computers, can benefit from the new technologies.

Methods

The aim of this project was to develop an application that enables patients to train language related tasks autonomously and, on the other hand, allows speech therapists to assign exercises to the patients and to track their results online. Seven categories with various types of assignments were implemented. The application has two parts which are separated by a user management system into a patient interface and a therapist interface. Both interfaces were evaluated using the SUS (Subject Usability Scale). The patient interface was tested by 15 healthy controls and 5 patients. For the patients, we also collected tracking data for further analysis. The therapist interface was evaluated by 5 speech therapists.

Results

The SUS score are $\bar{x}_{patients} = 98$ and $\bar{x}_{healthy} = 92.7$ (median = 95, SD = 7, 95% CI [88.8, 96.6]) in case of the patient interface and $\bar{x}_{therapists} = 68$ in case of the therapist interface.

Conclusion

Both, the patients and the healthy subjects, attested high SUS scores to the patient interface. These scores are considered as "*best imaginable*". The therapist interface got a lower SUS score compared to the patient interface, but is still considered as "*good*" and "*usable*". The user tracking system and the interviews revealed that there is room for improvements and inspired new ideas for future versions.

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Ich erkläre hiermit, dass ich diese Arbeit selbständig verfasst und keine anderen als die angegebenen Hilfsmittel benutzt habe. Alle Stellen, die wörtlich oder sinngemäss aus Quellen entnommen wurden, habe ich als solche kenntlich gemacht. Mir ist bekannt, dass andernfalls der Senat gemäss dem Gesetz über die Universität zum Entzug des auf Grund dieser Arbeit verliehenen Titels berechtigt ist.

Bern, January 31th 2015

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Contents

Contents	vii
1 Introduction	1
1.1 Speech and Language Disorders	1
1.2 Aphasia	2
1.3 Computer-Based Aphasia Therapy	3
1.4 Current Tablet Computer Applications	7
1.5 Aims of Thesis	7
2 Methods	9
2.1 Software Requirements Specification	9
2.2 Technical Implementation	10
2.2.1 General Concept	10
2.2.2 Patient Interface	11
2.2.3 Therapist Interface	14
2.2.4 Content Creation	16
2.3 Usability Testing	16
3 Results	19
3.1 SUS Patient Interface	19
3.2 SUS Therapist Interface	20
3.3 User Tracking	20
4 Discussion and Conclusions	23
4.1 Evaluation of the Patient Interface	23
4.2 Evaluation of the Therapist Interface	24
4.3 Conclusions	25
5 Outlook	27
Bibliography	29
List of Figures	31
List of Tables	31

Chapter 1

Introduction

1.1 Speech and Language Disorders

Speech and language impairments are subtypes of communication disorders. Although both terms are often used synonymously, one has to differentiate between them. Speech disorders refer to problems with speech production, such as the articulation of sound, the fluency (stuttering) and the voice. The following types of motor speech disorders can be observed:

1. **Apraxia of speech:** The stimulus from the brain to the mouth is interrupted. This may lead to an incorrect placement of the lip and mouth muscles, thus producing different speech errors such as sound distortions, substitutions etc. [4].
2. **Dysarthria:** Decreased coordination of movements, resulting in mumbling, slow rate of speech and abnormal pitch and rhythm when speaking [6].

On the other hand, language disorders concern the processing of linguistic information. This may involve the following four linguistic levels [5]:

1. The form of language
 - a. **Phonology:** The system of sounds and the rules that govern the sound combinations, for example *cold* - *clod*.
 - b. **Morphology:** The system that administers the structure of words and the construction of word forms.
 - c. **Syntax:** The system supervising the order of words to form sentences and the relationships among the elements within a sentence.
2. The content of language
 - a. **Semantics:** The meanings of words and sentences. Each term is memorized with related words, for example: *glass* - *water* - *wine* - *thirsty*.
3. The function of language
 - a. **Pragmatics:** The ways in which context contributes to meaning.

One can distinguish between disorders of language development in children and reductions of language in adults. The latter are acquired and may occur due to degenerative processes (e.g. dementia) or due to sudden brain lesions (e.g. an ischemic stroke or a traumatic injury).

1.2 Aphasia

Aphasia is an acquired language disorder, often accompanied by apraxia. The word *aphasia* originates from the Greek word *aphatos*, which means *speechless*. In fact, in rare cases the complete ability to communicate is affected, but rather several of the four linguistic modalities (reading, writing, speech production and comprehension) in different severity and combinations. Thus, aphasia is always a multi-modal language disorder, though intelligence is not concerned [13]. Aphasic impairments can be found on all four linguistic levels presented in the previous section.

As already mentioned, aphasia is always provoked by brain damages with lesions to the language relevant areas, namely Broca's area, Wernicke's area and the neural pathways connecting them. In most people, these areas can be found in the left cerebral hemisphere, as illustrated in Figure 1.1. In most cases, the reason for aphasia is a cerebral stroke (80 %), followed by trauma (10 %) and tumors (7 %), in rare cases inflammations, hypoxia and cerebral atrophy (each with 1 %). The location and the severity of the lesion is crucial for the variability of the different symptoms, resulting in different types of aphasia. Apart from language difficulties, patients also often experience neuropsychological and sensomotor problems, such as [19]:

- Apraxia of speech
- Neglect
- Hemianopsia
- Amnesia
- Diplopic images
- Hemiplegia/Hemiparesia
- Facial nerve paresis

In many cases all these listed impairments can lead to psychosocial problems.

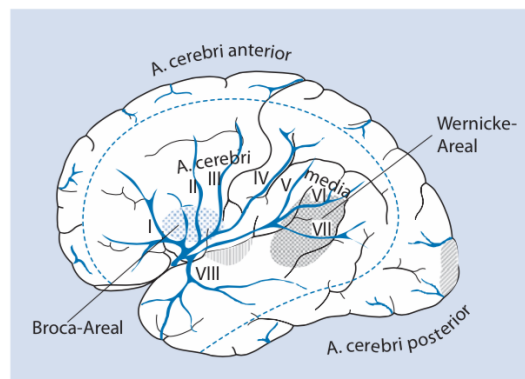


Figure 1.1. Blood supply and localisation-model of the language areas. Reprinted from Schneider B *et al.*, 2014 [19], with kind permission from Springer Science and Business Media

1.3 Computer-Based Aphasia Therapy

Whether the process of rehabilitation is successful or not depends to a large extent on the frequency of therapy. To reduce the load on therapist resources, the use of computers is an cost effective way to increase the intensity of therapy [14]. The first computer programs were developed more than 30 years ago. In a large group study with $n = 156$, Stachowiak [20] found out that patients who received computer training in addition to their regular therapist-delivered therapy, showed greater improvements than patients without computer training. Recent developments in tablet computers have opened new opportunities to use these devices for rehabilitation purposes. Especially older people, who have no prior experience with computers, can benefit from the new technologies. The manipulation of a touch screen, for example, is more intuitive and allows simpler UIs (User Interfaces). Furthermore, tablets are highly portable, allowing patients to easily take their devices wherever they want. Compared to paper and pen exercises, computers can give direct feedback to users and allow multimedia support, which can also increase the motivation to learn, as it has been shown by Kurland J. *et al.* 2014 [14].

A lot of literature can be found about software used in aphasia therapy running on personal computers and subscription-based websites. Less is known how new tablet computers can be used in this field. A computer literature search was performed in the PubMed database using the keyword "*iPad OR Tablet AND Aphasia*". Five out of the seven found articles were relevant. The reference lists of these articles were reviewed for additional studies with relevance to computer assisted therapy. Table 1.1 summarizes articles that fulfilled the inclusion criteria that the study must have at least five participants. A broader review covering computer-based therapy in general, including also studies with less participants and systematic reviews, can be found in Table 1.2.

Table 1.1. Overview on tablet-based therapy studies

Author	Type	Participants	Study Design	Method	Main Findings
Kurland J. <i>et al.</i> 2014 [14]	CP	N = 5; 55-81 years; >8 months post-single unilateral stroke	Case series	After 2 weeks of intensive language therapy, a HP program based on the iPad using iBooks Author software was used for maintaining and augmenting treatment gains. Words for objects and actions were retrieved. Half of these words had been trained and half were untrained during therapy.	All participants maintained advances. Motivation to use the technology and adequate training are more important factors than age, aphasia type or severity, or prior experience with computers.
Balachandran I. <i>et al.</i> 2014 [7]	JP	N = 55; age unknown; brain damage	Usability study	Using the Constant Therapy App, tasks in language and cognitive therapy had to be solved. Performance was determined using accuracy and latency measurements. If the performance exceeded 80%, the next level of difficulty of the task was assigned to the patient, or a different task examining the same skill.	All participants improved in their iPad-based therapy tasks in general, as well in accuracy as in latency. There is a huge need to continue longterm therapy for individuals with chronic brain damage.
Hoover E.L. <i>et al.</i> 2014 [12]	CP	N = 20; 43-72 years; wide range severities of aphasia	Case series	On completion of the BU ICAP (Boston University Intensive, Comprehensive Aphasia Program) program, participants received an iPad with an individualized HP program that included ongoing suggestions of ways to use the iPad to support their rehabilitation goals.	Significant improvements on discrete language areas targeted in treatment. The results also demonstrate statistically significant improvements on functional and quality-of-life measures.

HP = home practice; CP = conference proceedings; JP = journal publication

Table 1.2. Evidence-based summaries and relevant studies

Author	Type	Study Design	Main Findings
Aftonomos L. B. <i>et al.</i> 1997 [1]	JP	Case series	Significant improvement in chronic aphasia across a broad range of aphasia types and severities. Frequent and prolonged use of a computer software at home between treatment sessions, for practice of clinical exercises, self-stimulation, exploration, and communication support seems to have positive effects.
Fridriksson J. <i>et al.</i> 2012 [11]	JP	Case series	Online mimicking of audio-visual speech allows patients with Broca's aphasia to increase their speech output by a factor of >2. Speech entrainment that relies only on audition does not have the same beneficial effect. This suggests that seeing the mouth of the speech model provides crucial information that allows patients to increase their own speech output.
Manheim L.M. <i>et al.</i> 2009 [15]	JP	Delayed treatment design	Positive, albeit preliminary and limited, support for the use of a home-based computer-delivered language intervention program.
Archibald L.M. <i>et al.</i> 2009 [3]	JP	Usability study	Individuals who exhibited moderate-severe levels of aphasia pre-therapy showed a greater positive change than those with mild aphasia pre-therapy. Some preliminary evidence of a positive change in functional communication after a computer-based language therapy was found.
Allen L. <i>et al.</i> 2012 [2]	JP	Review of RCT's	Support for computer-based aphasia treatments.
Teasell R. W. <i>et al.</i> 2011 [23]	JP	Evidence-Based Review	Strong evidence from two studies that computer-based aphasia treatment can improve language skills at the impairment level. Limited evidence that improvements from computer-based treatment generalize to functional communication.
Ramsberger G. <i>et al.</i> 2014 [17]	CP	Case series	The use of a stylus can help patients with motor impairments.
Szabo G. <i>et al.</i> 2014 [22]	CP	Interview	Enlarging the text display and the use of a stylus are both strategies that facilitate the text selection process. Mobile devices can serve as an important tool to assist people with aphasia in their daily life communication.
Teodoro G. <i>et al.</i> 2013 [24]	CP	Case series	A virtual speech-driven clinician was used to supply script training. Both participants showed improvements.
Stark J. <i>et al.</i> 2013 [21]	CP	Interview	An integration of appropriate face-to-face language tasks and programs with computerized and, in particular, virtual applications can be seen as the best possible way to provide language rehabilitation to PWAs.
Mieke V. <i>et al.</i> 2011 [25]	JP	Paper summary	Open exercises that allow users to add their own words, sentences, and graphics are recommended. Online use of AAC tools is not suited in most cases. Disorder-oriented training programs can be made much more attractive by improving graphics, sound quality and interactivity. Interactive role-playing games with virtual communication partners can be used to train communicative scenarios.
Pedersen P. <i>et al.</i> 2001 [16]	JP	Case series	Computer-training can be effective both in the phonological and the semantic part if appropriate semantic tasks are chosen.
Cherney L. <i>et al.</i> 2007 [10]	JP	Case series	Virtual therapist computer treatment software may be a cost effective method of training conversational scripts for individuals with chronic nonfluent aphasia.

HP = home practice; CP = conference proceedings; JP = journal publication
 RCT = randomized control trials; PWA = people with aphasia; AAC = alternative and augmentative communication

The programs used in aphasia rehabilitation can be classified in the following three categories:

1. **Alternative and augmentative communication (AAC)**

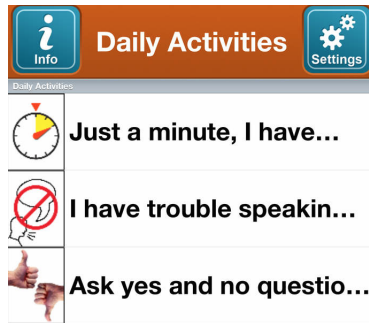
Typically a grid with symbols, pictures and sentences which can be pointed at and vocalized (consider Fig. 1.2). The problem with this approach is that aphasia is a multi or supramodal impairment, meaning that speech production can not be replaced by other means. That is the reason why AAC can only be used in patients with speech problems such as apraxia or dysarthria, but not with language disorders like aphasia [25].

2. **Computer-assisted treatment (CAT)**

Patient and clinician work side-by-side on the program, which has only a supportive function such as showing pictures (consider Fig. 1.3). The clinician has to evaluate the answers himself because the correctness can not be assessed automatically. He also has the responsibility for the therapy schedule.

3. **Computer-only treatment (COT)**

The program uses tasks that can be evaluated automatically, which allows adapting the difficulty of the exercises and the therapy schedule dynamically (consider Fig. 1.4). The patient is able to practice exercises by himself and is immediately getting a feedback if the answer is correct. In regular language therapy, speech therapists can give clues to patients to help them recalling words. The same can be done by COT apps by giving hints in form of pictures, audio recordings and videos.



(a) SmallTalk Daily Activities



(b) Proloquo2Go

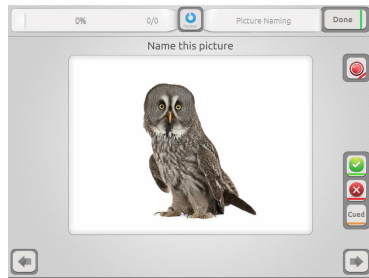


(c) GoTalk Now



(d) Verbally

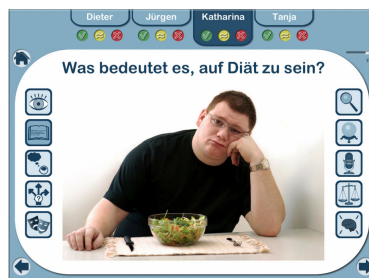
Figure 1.2. Selected alternative and augmentative communication (AAC) apps



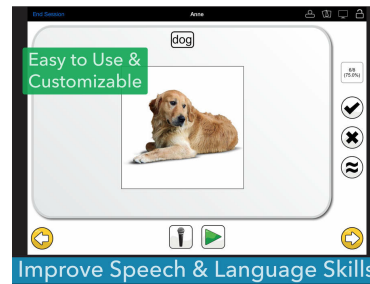
(a) Language Trainer



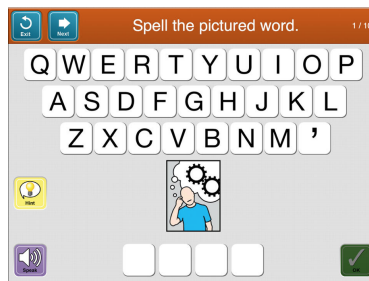
(b) Bildkarten für Logopäden



(c) Conversation TherAppy



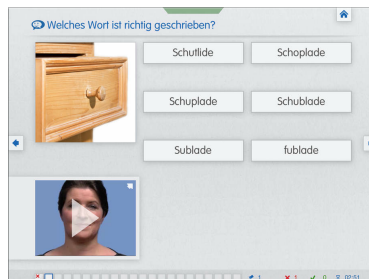
(d) Speech Cards Professional

Figure 1.3. Screenshots of selected computer-assisted therapy (CAT) apps

(a) TalkPath Therapy



(b) Language TherAppy



(c) Aphasie



(d) iName it

Figure 1.4. Screenshots of selected computer-only therapy (COT) apps

1.4 Current Tablet Computer Applications

An initial search (*date:11.8.2014*) with the keyword "*Aphasia*" returned 128 findings in the App Store (Apple, Inc.) and 95 findings in the Google Play Store (Google, Inc.). Relevant results were screened and are listed in Table 1.3. All of these apps are running on Apple devices (iOS), some of them also on Android (Google, Inc.) tablets.

The leading companies in aphasia rehabilitation software are: Constant Therapy, Lin-graphicare, Tactus Therapy Solutions, Attainment Company and Assistive Ware for native English speakers and SpeechCare for native German speakers. In collaboration with speech therapists from the Departement of Neurology at the Inselspital Bern we evaluated the usability and functionality of different apps. We found out that there is no state of the art application for native German speakers. Furthermore, we also revealed a lot of potential for improvements in all the other apps.

1.5 Aims of Thesis

The main objectives of this project can be summarized as follow:

- Development of a new application of the COT type running on an iPad tablet.
- Patients with aphasia can exercise independently at home.
- Speech therapists can assign tasks to patients and track their results online.
- Provide a platform for speech-therapists which allows them to create new exercises fast and easily.
- Usability evaluation of the application interface with brain-injured patients, healthy controls and speech therapists by using a questionnaire and a user-tracking system.

The idea is that patients can use the application in addition to regular therapy. Since aphasia is highly individual, the level of difficulty and contents of the tasks have to be continuously adjusted by the speech therapist.

Table 1.3. Current applications used in aphasia therapy

Name	Company/Developer	Ref.	Language			Price [CHF]	Free Trial	Features		Category		
			English	German	Others			Personalise	Recordings	CAT	COT	AAC
Constant Therapy	Constant Therapy, Inc	[7], ([12])	X			free ¹	X		X	X		
TalkPath Therapy	Lingraphica, Inc		X			free ¹	(X)		X	X		
The SmallTalk Family of Apps	Lingraphica, Inc	([18], [22])	X			free			X	X		
Aphasia	SpeechCare GmbH			X		55.-	(X)		X	X	X	
Bildkarten für Logopäden	SpeechCare GmbH			X		44.-			X	X		
Speech Trainer 3D	Smarty Ears		X			8.-			X	X		
Name it	Smarty Ears		X		X	15.-			X	X	X	
Language Trainer	Smarty Ears		X			15.-			X	X		
Reading Rehabilitation Toolkit	Smarty Ears		X		X	10.-			X		X	
Expressive	Smarty Ears		X			30.-		X				
Yes-No	Smarty Ears		X			2.-					X	
Language TherAppy	Tactus Therapy Solutions Ltd.	([22])	X			60.-	X		X	X	X	
Question TherAppy	Tactus Therapy Solutions Ltd.		X			34.-	X		X	X		
Speech FlipBook	Tactus Therapy Solutions Ltd.		X			free ²			X	X		
Conversation TherAppy	Tactus Therapy Solutions Ltd.		X			25.-	X		X	X		
GoTalk Now (Plus)	Attainment Company, Inc.		X		X	80.-/150.- ²	X			(X)		
Speech Tutor	Synapse Apps, LLC		X		(X)	10.-		X		X	X	
Describe it	Synapse Apps, LLC		X			9.- ²			X	X		
Language Forest	Synapse Apps, LLC		X			15.-		X		X	X	
Word Retrieval	Virtual Speech Center, Inc.		X			10.-			X	X	X	
Comprehension Aphasia	Virtual Speech Center, Inc.		X			20.-			X	X	(X)	
Reading Aphasia	Virtual Speech Center, Inc.		X			10.-			X	X	(X)	
Pictello	Assistive Ware	([22], [12])	X		X	19.-			X	X		
Proloquo2Go	Assistive Ware		X			220.-			X	X		
Proloquo4Text	Assistive Ware	([22], [12])	X			130.-			X	X	X	
VAST Songs Series	SpeakinMotion, LLC		X			15.-				(X)	X	
VASTix Series	SpeakinMotion, LLC		X			10.-/13.-				(X)	X	
All About Me Storybook	I Get It, LLC		X			3.-			X	X		
Talk'n Photos	Intermediate District 287		X			3.-			X	X	X	
Scene Speak	Good Karma Applications, Inc		X			10.-			X	X	X	
ChatAble	Therapy Box Limited		X		X	48.-			X	X	X	
Scene & Heard	Therapy Box Limited		X			160.-	X			X	X	
Predictable	Therapy Box Limited		X		X	5.-				X	X	
Minimal Pair Pack	Therapy Box Limited		X			100.-				X	(X)	
TalkRocket Go	MyVoice Inc.		X		X	22.-	X			X	X	
Talk Around IT Series	Neuro Hero Limited		X			80.-			X			
TalkTablet	Gus Communications, Inc.		X		X	9.-				X	X	
Keyword Understanding	Lorraine Curran		X			150.-						
TouchChat HD	Silver Kite		X		X	100.-	(X)				X	
MyTalkTools Mobile	2nd Half Enterprises LLC		X		X	3.-	X				X	
PhotoVoca	Cognable		X			10.-			X	X	X	
GuyTalk	No Tie, LLC		X			10.-			X	X	X	
Verbally Premium	Intuary, Inc.		X			100.-			X	X	X	
iSpeech	iSpeech, Inc.		X		(X)	free ²						
Speak it!	Future Apps, Inc.		X		X	2.- ²					X	
Speech Cards Professional	Robert Harrison		X			10.-	X					
Speech Sounds on Cue	Multimedia Speech Pathology		X			24.-	X			X		
Lexico	Pappy GmbH		X		X	20.-	X			X		

free¹ = Subscription service is needed; free² = In-App purchases
CAT = Computer Assisted Treatment; COT = Computer Only Treatment; AAC = Alternative and Augmentative Communication

Chapter 2

Methods

2.1 Software Requirements Specification

1. Purpose

Increase the frequency of language therapy for people with aphasia.

2. Product perspective

At the moment, there is only one relevant application for native German speakers. But the functionalities and the usability of this program can be improved to a great extent. This is also the case for many applications for native English speakers. For a complete overview of current apps used in aphasia therapy, the reader is referred to section 1.4.

3. Product functions

- The patient has to solve different language relevant tasks.
- Tasks are automatically assessed if solved correctly or not.
- The app provides hints in form of pictures, video and/or audio recordings.
- The patient can request additional help if he is not able to solve the task.
- Speech therapists can create new tasks easily by themselves without having any IT skills.
- Tasks can be assigned by the speech therapists to their patients.
- Record data about solved cards and the usage of the application.

4. User characteristics

The application will be used by two main groups: The speech therapists and the patients. Therefore, the requirements will be different. In general, patients are older people and have little experience with (tablet) computers. Often they have sensorimotor impairments and a reduced visual field. Therapists are used to work with (tablet) computers and have a lot of experience.

5. Constraints and assumptions

- Operating system: iOS
- Tablet computer: iPad
- Programming language: Objective-C
- Language: German
- Area of application: Inselspital Bern

2.2 Technical Implementation

2.2.1 General Concept

We decided to develop our application for the iOS platform (Apple, Inc.), since the Insel-spital Bern is already using this technology nowadays. In order to allow speech therapists to manage patient relevant data remotely and to create new tasks independently of the application, we decided to use a web server. For the server part we used parse.com, which is a Mobile Backend as a Service (MBaaS). This technology facilitates and speeds up the process for developers in order to use their applications in combination with a web server by providing them software frameworks.

The code for the iPad application was written in Objective-C. The reason is that most Cocoa Touch frameworks are implemented in Objective-C. At the beginning of this project, Apple released a new programming language called Swift, which is easier to learn and has a simpler syntax compared to Objective-C. Since many frameworks did not work properly and not much support was available at that point, we didn't switch over to Swift. The general

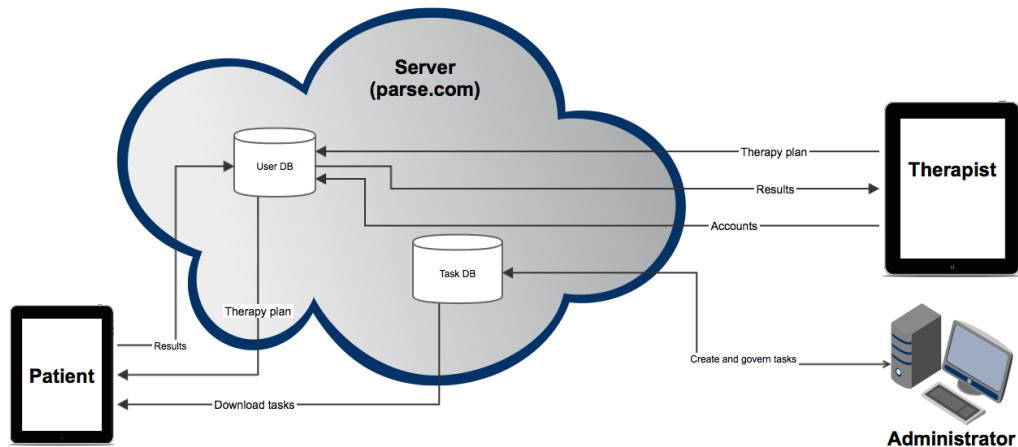


Figure 2.1. General concept

concept of this project is presented in Fig. 2.1. All interactions with the server are secured and require a login account. Although the application can be tested without entering any login credentials, a guest account will be created automatically in the background. Three types of users with different access rights interact with this system, as shown in Table 2.1. The iPad application itself has two different parts, one is the patient interface (shown on the left part in Fig. 2.1) and the other one is the therapist interface (shown on the right part in Fig. 2.1). These interfaces are separated by a user management system which requires login credentials. The card editor (for more details, see section 2.2.4) can be accessed via web browser and only a special type of user (administrator) is authorized to this system. Exercise cards are organized in decks and each category can hold several decks. In other words, decks act as a container which can hold several cards. This hierarchy level allows to separate the content with respect to its difficulty and semantic content.

Table 2.1. Access rights for different types of users

	Tasks	Statistics	Create patients	Create therapists
Patients	R	W		
Speech therapists	R	R	X	
Administrators	RW	RW	X	X

R = Read; W = Write

The whole workflow can be described as follows:

1. We, as the developers and privileged speech therapists (\rightarrow *administrator*) from the Inselspital Bern, can create new tasks and modify existing ones.
2. The speech therapist has to enter the login credentials on his iPad.
3. Then he creates new accounts for his patients.
4. Depending on the type and severity of aphasia, he assigns tasks with appropriate difficulty levels and contents to each patient.
5. The patient has to enter the login credentials given by the speech therapist on his iPad.
6. Assigned tasks are downloaded automatically to his iPad. The application keeps the login information and self-checks for available updates periodically every six hours.
7. Now the patient can start solving the assigned tasks on his iPad.
8. If the patient is connected to the internet, results are directly sent to the server. Otherwise they are stored locally and will be uploaded the next time the device is online.
9. The therapist can see results in real-time. Moreover, he can change or add new tasks at any time.

2.2.2 Patient Interface

In collaboration with the speech therapists, seven categories with different types of tasks (according screenshots can be found in Fig. 2.4) were defined. All tasks are based on well accepted language models and are also used in regular therapy. Further information can be found in Schneider B *et al.* 2014 [19].

Types of tasks:

1. **Relate images to a word**
A single word is shown and one has to select between up to six pictures.
2. **Relate words to an image**
A single picture is shown and one has to choose the corresponding word.
3. **Insert letters**
Single letters are given and one has to complete the word. Distractors can be used to increase the difficulty.

4. Complete sentences

Same as the previous task, but on sentence level.

5. Order letters

One has to bring the letters in the correct position. This task is without distractors.

6. Order words

Same as the previous task, but on sentence level.

7. Apraxia training

A video showing the pronunciation with the according word next to it.

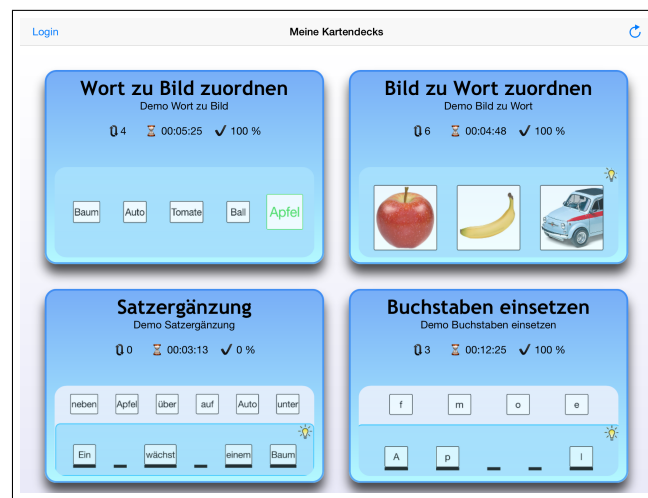


Figure 2.2. Homescreen of the patient interface

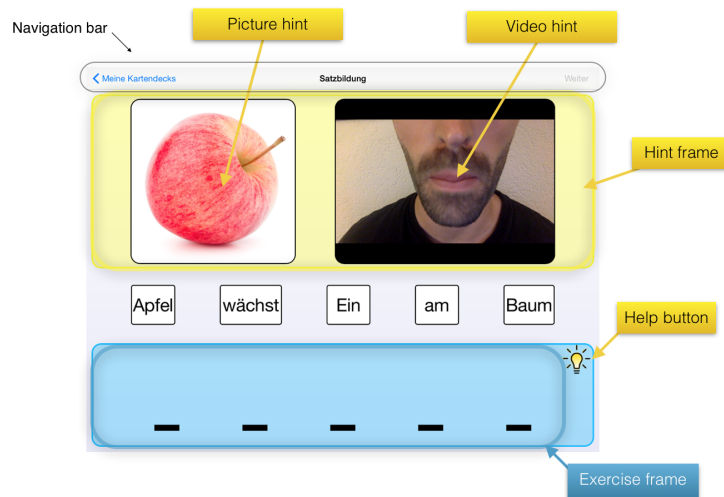
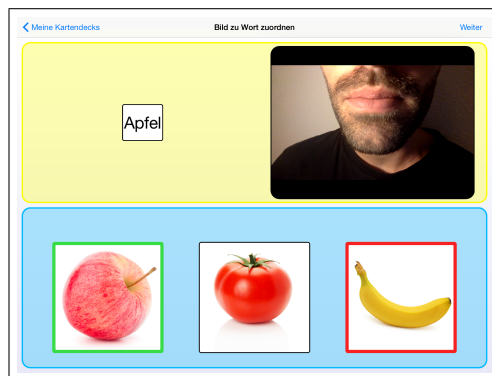
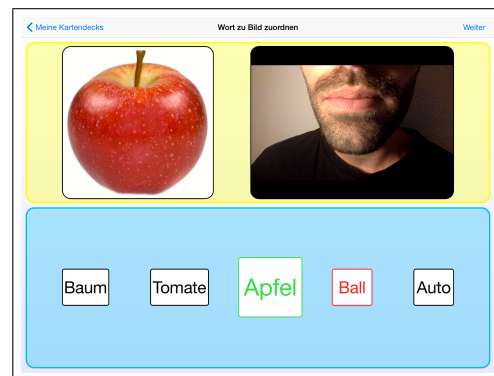


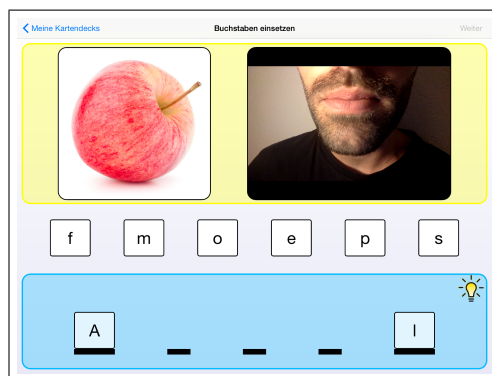
Figure 2.3. Composition of card elements



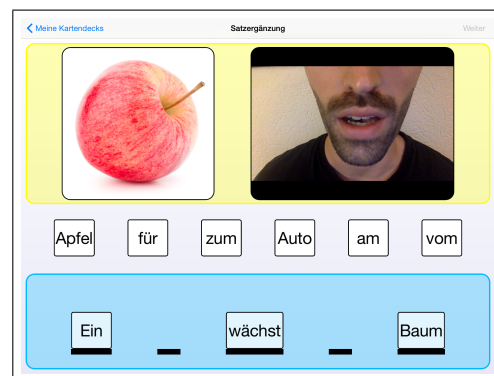
(a) Relate images to a word



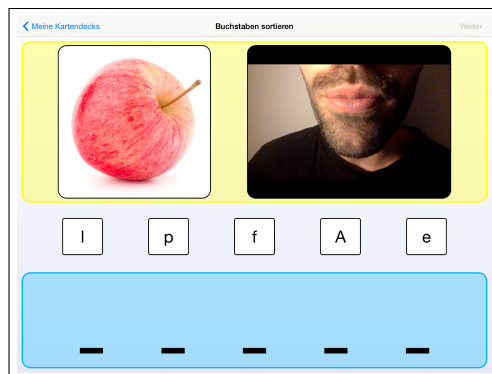
(b) Relate words to an image



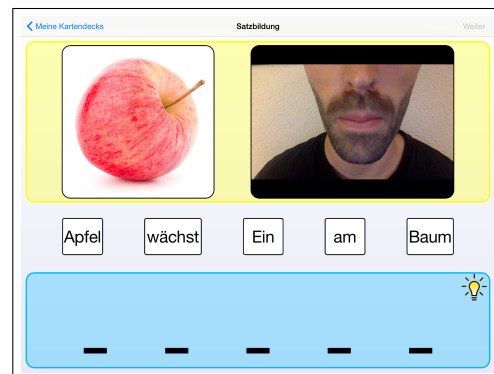
(c) Insert letters



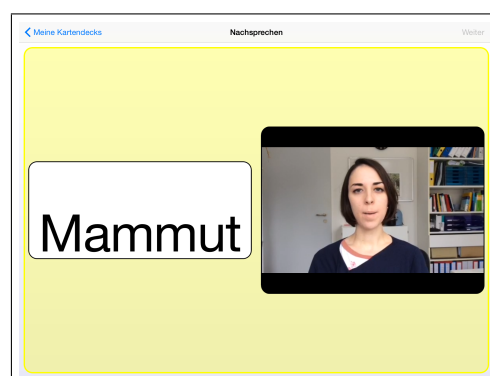
(d) Complete sentences



(e) Order letters



(f) Order words



(g) Apraxia training

Figure 2.4. All types of tasks

All assigned decks appear as blue boxes on the homescreen, as shown in Fig. 2.2. Each deck is composed by the following elements (from top to bottom):

1. An instruction title (type of task).
2. A designation (can be set for each deck individually).
3. The statistics: Number of iterations, time spent and percentage of correct answers.
4. An illustration describing the task.

By pressing on a deck, the corresponding cards are loaded and one can start exercising. The philosophy was to keep a consistency between the different types of tasks. We hope to achieve this by using recurring structures and distinctive colors. For all types of cards (with exception the apraxia task) we used the same screen layout, which can be found in Fig 2.3. The blue frame (hereinafter called *exercise frame*) in the lower screen part is where the patient is asked to solve a problem. The yellow frame (hereinafter called *hint frame*) in the upper screen part is used to give hints. They can occur in several forms:

1. A **video** showing the mouth movements pronouncing the word or sentence.
2. A **picture** showing the object or situation. A photograph is preferable to a drawing.
3. An **audio recording** vocalising the word or sentence.

Different combinations in giving clues are possible (e.g. a video and a picture, a picture only and so on). The amount and kind of support can be adapted on a card by card basis by the speech therapist for each patient individually. Further help can be provided by pressing on the light bulb (hereinafter called *help button*) showed in the upper right corner of the exercise frame. The manner of help depends on the selected category. Either a reduction of possible options will take place (tasks of type 1 and 2) or a check on the correctness, followed by one correct placement of a letter/word (tasks of type 3 to 6). Once the help button has been pressed, it will be hidden for the next 5 seconds to avoid an overuse.

In conclusion, the level of difficulty can be adapted by:

1. Turning on/off the help button.
2. Changing the amount and kind of clues shown in the hint frame.
3. The nature of the word/sentence itself (e.g. word/sentence length or semantic field).

2.2.3 Therapist Interface

As already mentioned, the therapist has a special type of account. Once he's logged in, he can see a different interface consisting of two pages. By using a swipe gesture, he can navigate between the user management and the task library. Screenshots of these two modes are provided in Fig. 2.5 and 2.6 respectively.

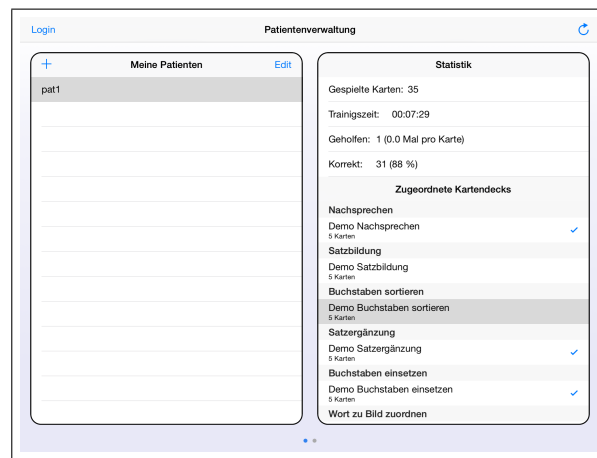


Figure 2.5. Patient management

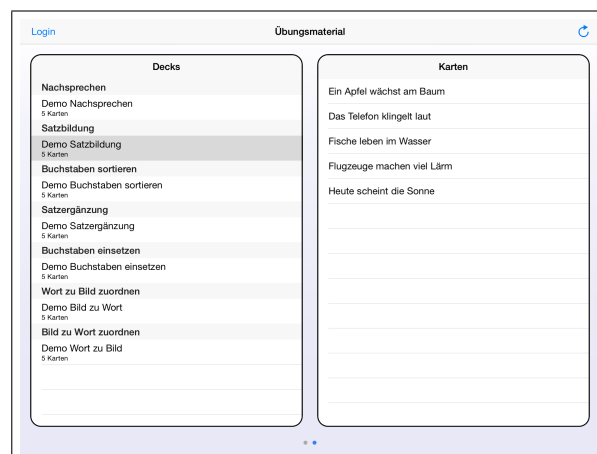


Figure 2.6. Library mode showing all available tasks

On the first page (patient management), the following functions are implemented:

- Create new accounts for patients by pressing the *"+" symbol*.
- Remove existing patients by pressing the *"Edit button"*.
- Show the statistics for each patient: The total number of played cards, the total play time, the mean value of pressing the help button per card and the percentage of correct answers are shown.
- Assign tasks to patients by touching on the corresponding deck. A checkmark will be set.

Whereas on the second page (library mode), all available decks and associated cards show up. By pressing on a single card, its content will be loaded and the therapist can see the card in the same manner as the patient would.

2.2.4 Content Creation

Until now, all tasks were created using the web interface of parse.com. The disadvantages with this method are:

- Technical skills are required.
- Error-prone for typos and incomplete entries.
- Tedious if plenty of tasks have to be created.

To solve these problems, we started building an online card editor. This one does not require any knowledge about the internal structure and lets selected speech therapists with administrator privileges easily create or modify existing tasks. The editor can be accessed by using any standard internet browser, although we only tested Firefox (Mozilla Corp.) so far. Although still under development, a preview is shown in Fig. 2.7. We used HTML, CSS as well as server- and client-based JavaScript code to build this website. The access to this editor is protected by a login system.

Figure 2.7. Early version of the web-based card editor

2.3 Usability Testing

To evaluate the usability of our application, we used the SUS (System Usability Scale) (Brooke, 1996). This assessment of usability is a simple, ten-item questionnaire with five response options ranging from strongly agree to strongly disagree, yielding a single number ranging from 0 to 100. The higher the value, the better the usability. SUS has become a standard in industry and is used to evaluate a wide variety of products and services on small sample sizes [9]. The SUS questionnaire can be found in the appendix. In addition to the questionnaire we implemented a tracking system for further internal analysis. This system recorded any user actions while the patients were solving tasks.

The usability test was separated into two parts: First we assessed the patient interface, second the therapist interface. Note that the card editor was not evaluated since it's still under development. For the patient interface, we asked the subjects to solve certain tasks.

For this reason, we created five demo tasks per category (= 35 tasks in total). Within a single category, the difficulty was increased by reducing the amount of support, as shown in Table 2.2.

Table 2.2. Structure of the demo deck used for the usability test

	Video hint	Audio hint	Picture hint	Help button
Card 1	X		X	X
Card 2		X	X	X
Card 3			X	X
Card 4				X
Card 5				

Each participant received an iPad in the initial state (homescreen showing the decks) and was asked to solve all tasks. No further instructions regarding the operation were given. In the patient group, the attending speech therapist was allowed to talk with the patient after 15 seconds in a situation where the patient had problems to solve a task regarding its content. 15 healthy subjects (age: 19 - 56 years; 5 female and 10 male) and 5 patients (age: 51 - 68 years, 1 female and 4 male) participated. The patients demographics can be found in Table 2.3. The inclusion criterion for the patients was a diagnosed aphasia in post-acute stage >6 weeks.

Due to the fact that the tracking system was not available from the very first, it only recorded the patients data and none of the healthy controls. The tracking data was exported from the server (parse.com) and analysed using a MATLAB-script that extracted relevant data from the JSON-file (JavaScript Object Notation). All healthy subjects were familiar to work with computers, most of them also with tablet computers. This was not the case for the patients, most of them had little experience with computers.

Table 2.3. Participating patients

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
Age	61	51	58	68	62
Sex	m	m	m	w	m
Aphasia a/d	16.05.2012	29.05.2014	31.07.2014	06.08.2013	23.05.2014
inpatient therapy a/d	30.05.2012	02.06.2014	11.08.2014	06.08.2013	04.06.2014
ambulant therapy a/d	28.08.2012	02.09.2014	25.11.2014	25.11.2013	22.07.2014

For the therapist interface we asked 5 speech therapists (5 female) from the Inselspital Bern to answer the SUS questionnaire. Many speech therapists already used tablets in their therapy sessions. The instructions we gave them were:

- Login with your therapist login account
- Add a new patient.
- Assign new tasks to the patient.
- Remove the patient you recently created.
- Explore the task library.

Chapter 3

Results

3.1 SUS Patient Interface

Individual SUS scores evaluating the patient interface are given in Table 3.1 and 3.2 respectively. The mean SUS score for the patient group is $\bar{x}_{patients} = 98$ and in case of the healthy control group $\bar{x}_{healthy} = 92.7$ (median = 95, SD = 7, 95% CI [88.8, 96.6]).

Table 3.1. SUS scores from the healthy control group

Subject	SUS score
Healthy 1	92.5
Healthy 2	100
Healthy 3	97.5
Healthy 4	97.5
Healthy 5	100
Healthy 6	100
Healthy 7	85
Healthy 8	82.5
Healthy 9	82.5
Healthy 10	97.5
Healthy 11	82.5
Healthy 12	100
Healthy 13	95
Healthy 14	87.5
Healthy 15	90

Table 3.2. SUS scores from the patient group

Subject	SUS score
Patient 1	97.5
Patient 2	97.5
Patient 3	97.5
Patient 4	97.5
Patient 5	100

3.2 SUS Therapist Interface

Individual SUS scores from the speech therapists evaluating the therapist part of the application can be found in Table 3.3. The mean SUS score is $\bar{x}_{therapists} = 68$.

Table 3.3. SUS scores from the speech therapist group

Subject	SUS score
Therapist 1	77.5
Therapist 2	60
Therapist 3	80
Therapist 4	65
Therapist 5	57.5

3.3 User Tracking

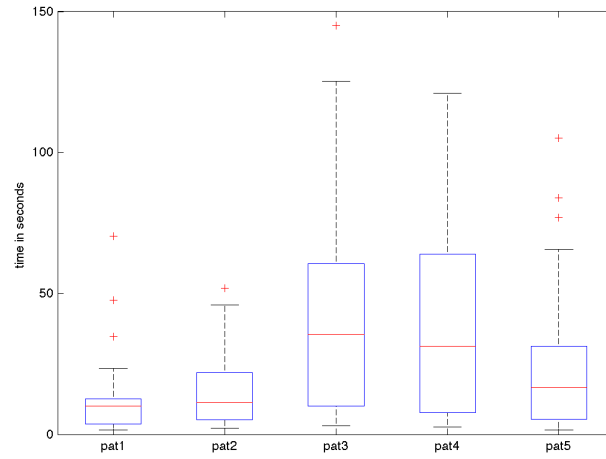
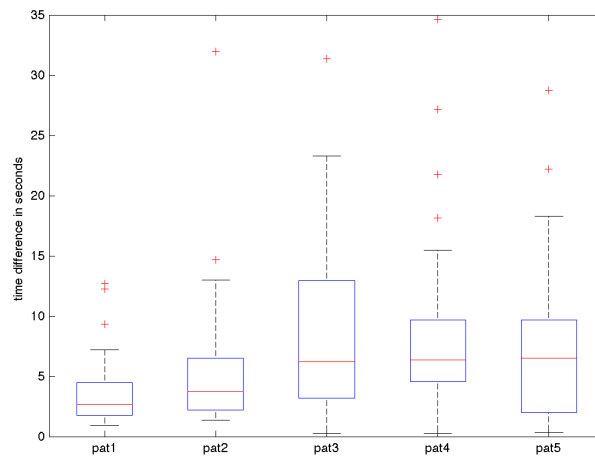
In Table 3.4, the tracked data is listed against the five patients, and in Table 3.5, against the seven types of tasks. For the visual representations of the time spent on a single card (until successfully solved) and of the time spent on a solved card (from successfully solved to moving to the next card), refer to Fig. 3.1 and Fig. 3.2 respectively.

Table 3.4. Tracked user data per patient

	Patient 1	Patient 2	Patient 3	Patient 4	Patient 5
Correct answers	88.6 %	100 %	71.4 %	45.7 %	60 %
Time spent on a card [s]	12.8	15.9	45.9	47	24
Time spent on a solved card [s]	4.5	5.3	8.4	12.9	7.5
Help button pressed [#]	1	0	1	16	2
Additional media playbacks [#]	2	1	19	18	13

Table 3.5. Tracked user data per category

	<i>Images to a word</i>	<i>Words to an image</i>	<i>Insert letters</i>	<i>Complete sentences</i>	<i>Order letters</i>	<i>Order words</i>	<i>Apraxia training</i>
Correct answers	100 %	80 %	68 %	60 %	52 %	52 %	(100 %)
Time spent on a card [s]	5.5	7.9	55.4	33.5	49.6	39	12.9
Time spent on a solved card [s]	4	7.6	5.8	14.3	9.1	9.7	3.7
Help button pressed [#]	0	0	4	3	6	7	0
Additional media playbacks [#]	4	3	2	8	2	7	27

**Figure 3.1.** Time spent on a card (35 cards)**Figure 3.2.** Time spent on a solved card (35 cards)

Chapter 4

Discussion and Conclusions

4.1 Evaluation of the Patient Interface

Both, the patients and the healthy subjects, attested high SUS scores to the patient interface. Using an adjective rating scale (for details see Bangor A. *et al.* 2009 [8]), both scores would translate to "*best imaginable*". It has been very pleasing that all patients were able to solve all tasks by themselves. Some patients were sceptical when we handed the iPad out to them. But after a short adaptation phase they gained confidence and were motivated to continue the assignments. The user tracking revealed that patients, by name patient 3, 4 and 5, who had more difficulties solving the tasks, in general needed more time to give an answer. They also claimed more often for support, either by replaying the videos or the audio recordings, or by clicking the help button. However, it has to be said that videos were replayed twice as much as audio recordings. An explanation for this might be that it was not obvious to replay an audio clue by just pressing into the hint frame. To make the availability of audio clues more clear, a possible solution would be to place an indicator symbol (for example a loudspeaker) or to autoplay the recording once at the beginning. The help button was only used extensively by patient 4 who had the most difficulties solving the tasks. Since the help button was not very well noticed by most participants, it should attract more attention while appearing on the screen. A possible solution might be to add animations or to play a supplementary sound. Patients with poorer results did also spend more time on a solved card before moving to the next one. Either they had more difficulties to remember what to do or they used the time for reflection and memorizing the solution. In contrast to most other programs, where proceeding to the next task is done automatically, we think it's a huge benefit that with our app the patient himself can decide when he wants to continue. This also prevents him getting confused because of a fast changeover.

Although we could not collect enough data for statistically significant results and the fact that tasks were not balanced, there is a trend in Table 3.5, that image-to-word linking tasks (or vice versa) were the easiest ones to solve correctly (100 % and 90 % respectively). Tasks where patients had to bring letters/words into a correct order were more difficult than tasks where some initial letters/words were given and they had just to insert the missing letters/words from a selection with distractors. Based on this, it would make sense to let the patients start the therapy with the easier image linking tasks in order to see their capability and then to increase the level of difficulty by moving to another category.

We perceived that at the beginning, patients as well as healthy subjects, intended to press on letter/word elements for the placement instead of dragging. Nevertheless, we believe that the possibility to drag elements allows more flexibility, since some patients started building the sentences or words not straight from the left side. They also appreciated the opportunity to make adjustments. The same is not possible with all applications from the competition. Some subjects (patients as well as healthy controls) had problems to figure out how to proceed from a solved task to the next one. While after a certain time all participants touched on the next button in the navigation bar, fewer were using the swipe gesture. To make this gesture more obvious, we could, for example, implement a carousel animation which advances the card from the right to the left while clicking on the next button. This will tell the user that the screen has become sensitive to swipe gestures after having solved the task, so the next button helped him to discover this gesture.

4.2 Evaluation of the Therapist Interface

While a SUS score of 68 points for the therapist part is still considered as *"good"* and *"usable"* (using again the adjective rating scale from Bangor A. *et al.* 2009 [8]), the score was much lower than for the patient part. Since we decided to spend more time on the patient interface than on the therapist interface, this might explain the differences in the SUS scores. The reason for the unequal use of time is justified by the fact that more patients than therapists will use the application. Although the therapist interface fulfils all the required functions, there is still room for improvements concerning the GUI (Graphical User Interface). The therapists stated that they had to learn a lot about how to use the different functionalities, like changing from the patient management mode to the library mode, creating new patients or assigning tasks. Possible solutions to these problems might be:

- Additional tab bar at the bottom of the screen to indicate how to switch between the patient management mode and the library mode.
- In the patient management mode, the frame with the statistics and assigned tasks is hidden until a patient is selected.
- A tutorial will explain briefly the purpose and the particular features. The tutorial can be shown during the login process or on demand.

To make the GUI more appealing, we collected the following ideas:

- Show preview images in the library mode for each card.
- Use more graphical elements for the statistics (e.g. progress bars).
- Rearrange the elements in the patient management mode (e.g. by using a split view) to gain more space.

4.3 Conclusions

Based on the SUS scores, it can be concluded that the usability of the app is well accepted by the users. The design for the patient interface has shown to be clear and consistent, so patients can use the app independently at home. The content and difficulty can easily be adapted to the needs of each patient in order to keep him challenged and motivated.

The therapist interface is fully functional, but not as intuitive to use as the patient interface and needs minor revisions. Until now, the content for tasks has to be defined using the web interface of parse.com, since the online card editor could not get finished on time.

Chapter 5

Outlook

This project will be continued beyond this thesis. The next steps will be:

1. **Finalization of the card editor**
File upload and validity check for entries (e.g. no empty fields or too long words/sentences). Decks can be classified by a description field or using tags. Speech therapists can access the patient data in the web application.
2. **New exercise cards** In co-work with the speech therapists, 50 new cards per category (=350 cards in total) will be added.
3. **Improvement of the patient interface**
Apply the ideas proposed in section 4.1. Change the design of the homescreen and improve the offline availability.
4. **Improvement of the therapist interface**
Apply the ideas proposed in section 4.2. The amount of support can be set globally for each patient.
5. **New functionalities**
Therapists can create a login account for themselves directly in the iPad application. Different audio/video hints are used instead of replaying the same clue over and over.
6. **Testing**
Check for all functionalities in different scenarios on several devices. Check for problems if the internet connection is disturbed.

Last but not least, the app will be released on the App Store (Apple, Inc.) and made available for everyone to download.

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List of Figures

1.1	Blood supply and localisation-model of the language areas	2
1.2	Selected alternative and augmentative communication (AAC) apps	5
1.3	Screenshots of selected computer-assisted therapy (CAT) apps	6
1.4	Screenshots of selected computer-only therapy (COT) apps	6
2.1	General concept	10
2.2	Homescreen of the patient interface	12
2.3	Composition of card elements	12
2.4	All types of tasks	13
2.5	Patient management	15
2.6	Library mode showing all available tasks	15
2.7	Early version of the web-based card editor	16
3.1	Time spent on a card (35 cards)	21
3.2	Time spent on a solved card (35 cards)	21

List of Tables

1.1	Overview on tablet-based therapy studies	3
1.2	Evidence-based summarys and relevant studies	4
1.3	Current applications used in aphasia therapy	8
2.1	Access rights for different types of users	11
2.2	Structure of the demo deck used for the usability test	17
2.3	Participating patients	17
3.1	SUS scores from the healthy control group	19
3.2	SUS scores from the patient group	20
3.3	SUS scores from the speech therapist group	20
3.4	Tracked user data per patient	20
3.5	Tracked user data per category	21

Appendices

System Usability Scale (English)

N°.....

AGE.....

Strongly
disagree

Strongly
agree

1. I think that I would like to use this system frequently

1	2	3	4	5

2. I found the system unnecessarily complex

1	2	3	4	5

3. I thought the system was easy to use

1	2	3	4	5

4. I think that I would need the support of a technical person to be able to use this system

1	2	3	4	5

5. I found the various functions in this system were well integrated

1	2	3	4	5

6. I thought there was too much inconsistency in this system

1	2	3	4	5

7. I would imagine that most people would learn to use this system very quickly

1	2	3	4	5

8. I found the system very cumbersome to use

1	2	3	4	5

9. I felt very confident using the system

1	2	3	4	5

10. I needed to learn a lot of things before I could get going with this system

1	2	3	4	5